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Immediate Response of Black Basses to Dam Removal Is Determined by Habitat Preference

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M.S. Thesis Defense

Immediate response of black basses to dam removal is determined by habitat preference

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<A> Abstract

Dams affect the abundance of fish species in lotic systems by altering flow regime and available physical habitat. Removal of dams may mitigate these effects and generate a change in species abundance and fish community structure. Understanding the effects of dam removal on gamefish species is essential in making management decisions. I investigated how populations of Smallmouth Bass (*Micropterus dolomieu*), Spotted Bass (*M. punctulatus*), and Largemouth Bass (*M. salmoides*) were affected by the presence and removal of two low-head dams in a Midwestern river system. I used data collected during fall and spring from 2012-2015 (pre-removal) and 2018-2019 (post-removal) using multiple gear types at six study sites on each river; two within the run-of-river reach, two within the impounded reach, and two within the downstream reach. I analyzed species abundances using a nested ANOVA with fixed factors of season, reach, and dam removal, within the random factor of river. The interaction of season and treatment factors, along with all other individual factors, significantly affected Smallmouth Bass abundance. Only the interaction of season and treatment factors affected Largemouth Bass abundance, and only the factor of season affected Spotted Bass abundance. Impounded reaches had lower Smallmouth Bass abundance pre-removal. Overall Smallmouth Bass abundance increased post-removal, while Largemouth Bass and Spotted Bass abundance decreased. These results demonstrate an immediate response in a sport fishery to dam removal and suggest that Smallmouth Bass may benefit from dam removal as a form of habitat restoration and gamefish management.

<A> Introduction

Artificial dams are pervasive in river systems today, with over 2,000,000 estimated in the United States alone (Shuman 1995; Graf 1999). These dams were constructed primarily during the early part of the twentieth century for the purposes of irrigation, water storage, flood control, hydropower, and recreation. As of 2020, up to 80% of dams in the United States were at least 50 years old, and many require repair or removal (Bellmore et al. 2016). The past two decades has seen an increase in dam removals as many dams no longer serve their intended purpose, pose public safety risks, and affect the aquatic ecosystems in which they are present (Doyle et al. 2000; Jansson et al. 2007). With the increased dam removal rate comes a need for scientific evaluation to inform sportfish management decisions surrounding dams and their removal.

The presence of a dam alters the flow regime of a river system and may create three spatially distinct areas. First, the area immediately upstream of the dam will be subject to a pooling effect causing a shift from lotic to lentic type habitat with decreased water velocity, increased water temperature, and sediment loading (Bednarek 2001; Doyle et al. 2003). Second, the habitat immediately below the dam may be altered as water velocities become affected by the dam structure, resulting in habitat alterations through periods of torrential flow and streambed scarification, or periods of little to no flow and sediment compaction (Kondolf 1997; Stähly et al. 2019). Third, the river above the impounded reach may lose species richness and genetic diversity through loss of habitat connectivity (Bunn and Arthington 2002; Jansson et al. 2007; Catalano et al. 2007), although the physical habitat may not be affected in this reach as the flow regime remains unchanged.

Fish population response to the presence of a dam structure may manifest itself in a variety of ways. Changes to available physical habitat, such as a loss of habitat complexity in the impounded reach due to sediment deposition, may favor certain species of fish but put others at an adaptive disadvantage (Bunn and Arthington 2002). Loss of in-stream connectivity also restricts seasonal movements of fish, temporal access to spatially distinct resources, and leads to isolated populations that lose genetic diversity (Jansson et al. 2007). The result is often a decrease in biodiversity through loss of river-obligate species to generalist species that may persist in degraded habitats (Bunn and Arthington 2002). These damming effects may persist so long as the structure is present.

River restoration through dam removal focuses on returning lotic communities to riverine habitat and reestablishing the natural connectivity present before impoundment. Restored connectivity allows fish species to regain access to resources important to their life histories (Bunn and Arthington 2002). Physical habitat may also change following the removal of a dam structure through the migration of sediment deposit out of the impounded area as the river carves a new channel (Doyle et al. 2000). The loss of fine sediments may restore availability of physical habitat such as coarse substrates and affect distributions of lotic species (Kanehl et al. 1997; Bushaw-Newton et al. 2007). Physical habitat changes following dam removal and subsequent responses by fish species may occur along variable timelines (Dorobek et al. 2015) and depend on the size and type of dam structure (Doyle et al. 2005), geomorphology and type of stored substrate (Doyle et al. 2003), hydrologic factors (Wang et al. 2020), and the state of the fish community before removal (Catalano et al. 2007).

Despite increased dam removal efforts, there is a lack of scientific study surrounding dam removal, with few studies including pre-removal and post-removal data (Doyle et al. 2000; Bellmore et al. 2016). Additionally, the mechanisms driving the effects of dam removal on fish remain somewhat obscure and may differ between dams. For example, both low-head dams examined in this study were previously researched in an unrelated project which found minimal siltation occurring above the dams (Csiki and Rhoads 2014), suggesting factors besides habitat degradation may drive changes seen in the fish community. However, another low-head dam study conducted in northern Illinois revealed severely degraded habitat scores in the impounded reaches with an observed effect on the distribution of riverine fishes, suggesting dams indeed degrade habitat upstream and affect fish populations (Santucci et al. 2005). Despite this uncertainty, studies have shown that dams can impact habitat and the functional composition of fish communities (Smith et al. 2017), and that dam removal can benefit fish communities and individual sportfish populations such as *Oncorhyncus* species in the western United States (Allen et al. 2016) and Smallmouth Bass in the Midwest (Kanehl et al. 1997). This presents an opportunity to increase the resolution of research on dam removal as a restoration and sportfish management strategy.

Streams of the Midwestern United States often contain co-occurring populations of black basses including Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*Micropterus salmoides*), and Spotted Bass (*Micropterus punctulatus*). These black bass species serve important ecologic roles as top-level predators and are economically importance as the most popular group of gamefish in the United States (Division of Federal Aid, U.S. Fish and Wildlife Service 1999). Smallmouth Bass are known to prefer habitat associated with lotic systems (McLendon and Rabeni 1987; Lobb and Orth 1991; Scott and Angermeier 1998; Ettinger-Dietzel et al. 2016), Largemouth Bass are known as more lentic adapted species (Goclowski et al. 2013), and Spotted Bass are more of a habitat generalist (Warren 2009). Although each species has slightly different habitat requirements, they have niche overlap and may compete for resources (Hodgson et al. 1997; Long and Fisher 2000).

The presence of three competing species with differing habitat characteristic preferences in a previously impounded system presented an opportunity to investigate how a riverine black bass community responds to dam removal. Pre-removal and post-removal data were collected for two associated streams in Illinois. I hypothesized that dam removal would significantly increase the abundance of the more lotic-adapted Smallmouth Bass, significantly decrease the abundance of the more lentic-adapted Largemouth Bass, and have no significant effect on the abundance of the generalist Spotted Bass. Furthermore, I predicted changes in species abundance would be driven by changes in physical habitat availability following dam removal.

<A> Methods

Study Area- I conducted this study on the Vermilion River and North Fork Vermilion River in east-central Illinois. The Vermilion River system drains an area of approximately 3,341km^2 at the lowest reaches of the study site (IDNR 2018) and is characterized by a diverse fish community which includes Illinois state threatened and endangered species and three species of black basses. Each river was impounded by a low-head dam until the removal of the Danville dam on the mainstem Vermilion River in the fall of 2018, and the removal of the Ellsworth dam on the North Fork Vermilion River in the spring of 2019. I used data collected before and after the removal of both dams during the spring and fall from 2012-2015 and 2018-2019 at six study sites on each river (Figure 1). Each river contained two study sites located within the run-of-river reach, two within the impounded reach, and two within the downstream reach.

Habitat Assessment- Habitat quality measurements were taken before and after dam removal using modified Ohio Qualitative Habitat Evaluation Techniques (QHEI) described in Rankin (2006). Surface water velocity measurements were taken from the thalweg using a Hach Portable Velocity Meter at the longitudinal center of each site during each sampling event. Water quality parameters taken included surface temperature, conductivity, pH, and turbidity. Habitat scores and water velocities were analyzed for differences between reaches and differences before and after dam removal using a two-way analysis of variance (ANOVA) with post hoc Tukey's HSD tests. Water velocities were separated by season to account for variability in discharge. All statistical analyses were performed using R version 3.6.3 (R Core Team, 2020).

Fish Sampling- Assessment of the fish community on the Vermilion River took place once during the fall and spring each year of the study using boat mounted pulsed DC electrofishing setup running off of a 4,000 watt generator (60 hertz, 25% duty cycle) with two

Wisconsin droppers and one dip netter. Assessment of the fish community on the smaller North Fork Vermilion employed the same methods before the removal of the Ellsworth dam; however, drastically lower water levels following removal required the use of a barge electrofishing unit for sampling. Barge surveys were completed using the same generator and output as the boat electrofisher, but with three anodes and three dip netters. All surveys used thirty minutes of shocking effort to cover all habitats within each 100-meter study site. All fish were collected, identified to species, measured for total length, weighed, and released. Only black bass species data was analyzed. Catch per unit effort (number of fish per hour) was used to estimate species abundance at each site.

Black Bass Population Assessment- To identify black bass species responses to dam removal, a Type III nested ANOVA using Satterthwaite's method in R package lme4 (Bates et al, 2015) was used. River was set as a random factor with fixed factors of reach, season, and dam removal to identify effects on the catch-per-unit-effort (CPUE) of each bass species. CPUE was $\log_{10}+1$ transformed to maintain homogeneity of variance among data. An identical analysis was run using $\log_{10}+1$ CPUEs which had been transformed using multigear mean standardization (MGMS) described in Gibson-Reinemer et al. (2016) to identify any differences in the analysis which may have resulted from using multiple gear types. Total lengths were compared pre-and post-removal using a Wilcoxon rank-sum test to assess changes in the size of each black bass species. Relative conditions (Kn) were calculated based on methods described by Le Cren (1951) and were compared pre- and post-removal using a Wilcoxon rank-sum test to assess changes in fish condition. Proportional size distribution (PSD) values were calculated based on stock lengths found in Gabelhouse (1984) and were also compared pre- and post- removal using a

Pearson's Chi-square test to assess changes in the quality of the black bass fishery. All statistical analyses were performed using R version 3.6.3 (R Core Team, 2020).

<A> Results

Habitat- As expected, QHEI scores showed significant differences between all reaches (ANOVA, $F_{2,30} = 8.0977$, $P < 0.001$), but they did not show significant differences post-removal compared to pre-removal (Table 1). Scores were found to be lowest in the impounded reaches in both rivers (Figures 2, 3). Fall water velocities differed significantly between reaches (ANOVA, $F_{2,72} = 8.0977$, $P < 0.001$; Table 1), with a Tukey's Post Hoc test showing those differences occurring between the run-of-river reaches and impounded reaches ($P < 0.01$), and between the impounded reaches and downstream reaches ($P < 0.01$). Dam removal had no effect on fall water velocities. In contrast, spring water velocities were not different between reaches but were significantly higher following dam removal (ANOVA, $F_{1,18} = 0.86640$, $P = 0.004$; Table 1, Figure 4).

Black Bass Populations- A total of 626 black basses were collected during the study; 411 from 2012-2015 before dam removal, and 215 from 2018-2019 following removal. Of those collected, 242 were Smallmouth Bass, 204 were Largemouth Bass, and 180 were Spotted Bass. Rivers were roughly equivalent with the North Fork Vermilion River having 299 of the black basses sampled and the Vermilion River having 327.

Results from identical tests using data adjusted through MGMS identified the same factors as significant for all species, although P-values differed slightly. This is likely due to individual values being adjusted to reflect their relation to the mean abundance of respective surveys rather than being analyzed as a raw data point. Additionally, similarity of active gear types appeared to have little differences in efficiency and did not affect results as one would expect when combining active and passive gear types. I included three-way interactions in the nested ANOVA, but results were non-significant and thus omitted.

As hypothesized, Smallmouth Bass abundance increased overall and was significantly affected by the interaction of season and dam removal ($F_{1, 101} = 14.75$, $P < 0.001$) and by independent factors of reach ($F_{2,101} = 8.13$, $P < 0.001$), season ($F_{1, 101} = 8.87$, $P = 0.003$), and dam removal ($F_{1,101} = 4.53$, $P = 0.036$; Table 2). Expectedly, Smallmouth Bass abundance was lowest in the impounded reaches pre-removal and post-removal (Figure 5). All reaches showed increases in abundance during the fall, but only the impounded reach showed an increase during the spring. System-wide Smallmouth Bass total length increased minimally following dam removal and was non-significant using (Table 3). Despite this, the small change was reflected in an increased PSD from 74 to 88 but was also non-significant (Table 4). Smallmouth Bass relative condition slightly decreased following dam removal, but this was also found non-significant (Table 3).

Not surprisingly, Spotted Bass abundance was only affected by the fixed factor of season ($F_{1,102} = 8.87$, $P = 0.004$; Table 2), with no effects of dam removal, reach, or interactions between factors. Higher abundances of Spotted Bass occurred during fall surveys than during spring (Figure 6). Total length of Spotted Bass decreased slightly, yet significantly, following dam removal ($W = 2460$, $P = 0.029$; Table 3) and significantly decreased the Spotted Bass PSD ($X^2 = 13.576$, $DF = 2$, $P = 0.001$; Table 4). Spotted Bass condition remained constant following dam removal (Table 3).

Largemouth Bass abundance was found to be significantly affected only by the interaction of fixed factors season and dam removal ($F_{1,102} = 6.83$, $P = 0.01$; Table 2). MGMS transformed data corroborated these findings with slightly different P-values. Largemouth Bass abundance decreased across all reaches during spring surveys but only decreased in the downstream reaches during fall surveys, illustrating an effect only created when considering dam removal mediated by season (Figure 7). Largemouth Bass total length decreased significantly following removal (W = 2474, P = 0.008; Table 3) but did not significantly affect PSD, although a slight decrease was observed. Largemouth Bass relative condition did not change significantly post-removal (Table 3).

<A> Discussion

Habitat- Habitat quality was significantly different among reaches before and after dam removal, with the lowest QHEI scores occurred in the impounded reaches where habitat degradation is expected. A higher proportion of fine substrates and lack of habitat complexity caused by the pooling effects of the dam is a likely the cause for poor habitat in this reach. The observed habitat degradation in the impounded reach is consistent with other studies (Kanehl et al. 1997; Santucci et al. 2005), however system-wide habitat scores were not significantly different following dam removal. Sediment migration and channel restructuring can occur at varying rates (Doyle et al. 2003), and so the lack of significant changes is not surprising given the limited temporal scope. Interestingly, habitat scores dropped immediately downstream of the former Ellsworth dam site (Figure 3). This is likely due to fine substrates transported downstream but should be a temporary change in habitat quality.

The observed increase in spring water velocities following dam removal is likely the result of a more uniform stream gradient. The dams previously maintained a level surface elevation slowing the flow, but water flowed unimpeded and reached higher velocities with the dams removed. Despite this, the unchanged water velocities during the fall following dam removal may be because the rivers were at base-flows and subject to pooling or meandering within all reaches even following removal. Still, water velocities differed between the run-of-river and impounded reaches during the fall, indicating lingering effects of the impoundments on water movement.

Smallmouth Bass- Consistent with my hypothesis, Smallmouth Bass abundance increased following dam removal. This is not surprising as Smallmouth Bass are a more lotic adapted species than the other black bass species found in the study area (Scott and Angermeir 1998;

Goclowski et al. 2013). One mechanism that may drive the response of Smallmouth Bass to dam removal is the new availability of preferable physical habitat. Smallmouth Bass have been demonstrated to prefer water velocities, substrate sizes, cover types, and mean depths common to lotic systems (McLendon and Rabeni 1987; Lobb and Orth 1991; Ettinger-Dietzel et al. 2016). Additionally, Smallmouth Bass prefer a heterogenous environment of gravel, cobble, boulders, and snags (Orth and Newcomb 2002), and their abundance is negatively related to an increase in fine sediments (Brewer and Rabeni 2011). With the dams in place, the impounded reach likely offered less preferable habitat for Smallmouth Bass than the other two reaches due to decreased flow and sediment deposition. QHEI scores were reduced with the presence of fine substrates and lack of in-stream cover in the impounded reaches, both of which are not preferable habitat characteristics of Smallmouth Bass. The removal of the dams likely began changing habitat availability and invited a shift in Smallmouth Bass distributions through restoring flow regime and initiating the removal of fine sediments built up in the impounded reach.

Smallmouth Bass abundance may also increase following dam removal through enhanced recruitment as they prefer nesting sites in gravel substrates close to cover such as rocks, ledges, boulders, and woody debris (Orth and Newcomb 2002). Fine sediments may be removed rapidly from a previously impounded section of river following dam removal (Doyle et al. 2002), and expose suitable nesting habitat for Smallmouth Bass, increasing recruitment. This was observed in a study on the Woolen Mills dam removal on the Milwaukee River where total lengths of Smallmouth Bass decreased as abundance increased, pointing to increased recruitment (Kanehl et al. 1997). Although spawning habitat availability has been demonstrated to increase recruitment, this was likely not a main factor driving the increased abundance observed. Total lengths of Smallmouth Bass did not change significantly during our study. While the effect of changed recruitment may not be captured in the short time span of this study, it is important to note that the lowest Smallmouth Bass CPUEs were seen in the impounded reaches during the spring sampling events both before and after dam removal. This points to temporal avoidance of these areas during spawn, likely in response to unsuitable spawning habitat before dam removal and the lingering effects on substrate and in stream cover following removal. Dam removal may restore much of this habitat and lead to increased recruitment in the future. This is further supported by the only observed increase of Smallmouth Bass abundance during the spring occurring in the impounded reach, indicating increased use of changed habitat during the spawning season.

The increase in Smallmouth Bass abundance points to an immediate behavioral response by Smallmouth Bass to occupy newly available habitat. Changes in size or condition would be driven by other mechanisms such as trophic cascade or recruitment and would require a larger temporal scale than my study provides to capture. No changes were seen in the total length, PSD, or condition of Smallmouth Bass following dam removal, and so recruitment or forage availability, among other factors driving these metrics, are not likely tied to the increased abundance.

Spotted Bass- Consistent with my hypothesis, Spotted Bass abundance was not affected by any other factor than season. The lowest abundances of Spotted Bass were seen during spring surveys and may have been a result of temporal habitat use and decreased sampling efficiency, as Spotted Bass have been observed to use near-bank habitats less frequently during spring (Edge et al. 2020). However, I do not believe efficiency played a role in the results of the other two species as their abundance levels overlapped considerably between fall and spring sampling events.

Spotted Bass are a generalist species and can persist in a variety of lentic and lotic environments (Tillma et al. 1998; Warren 2009), so lack of responsiveness to dam removal was expected. Spotted Bass overlap habitat with Largemouth Bass (Goclowski et al. 2013) and Smallmouth Bass but have been observed to prefer more lentic environments than Smallmouth Bass (Scott and Angermeier 1998). Dam removal and reach did not affect Spotted Bass abundance, and any associated changes in habitat are not expected to directly affect Spotted Bass abundance in the future.

It is possible Spotted Bass abundance may be related to factors such as interspecific competition or recruitment rather than habitat when in sympatry with other black basses. All three black bass species in this system overlap diet on some level (Long and Fisher 2000), and Largemouth Bass can infringe on forage availability for other piscivores (Hodgson et al. 1997). Therefore, changes in the populations of competing species may affect the Spotted Bass community.

Although not affecting abundance, dam removal did significantly decrease the lengths of Spotted Bass. This may be an example of Spotted Bass response to changes in the Smallmouth Bass and Largemouth Bass populations, although the exact mechanisms behind it would require further study. One possible explanation may be reduced predation of smaller Spotted Bass following the decrease in Largemouth Bass. Predation by other black basses is a known source of mortality for Spotted Bass (Raborn et al. 2003), and reduced predation of smaller fish by Largemouth Bass may have minimally shifted the size structure. Spotted Bass PSD values dropped steeply following removal (Table 4), but this is likely because most individuals surveyed were below stock size which resulted in a very small sample size used to calculate a PSD value.

Largemouth Bass- As I hypothesized, Largemouth Bass decreased in abundance following dam removal, but only during the spring. A decrease in Largemouth Bass abundance following the removal of the dams was expected as it is a more lentic-adapted species preferring habitats with lower water velocities, higher temperatures, and more embedded substrates (Goclowski et al. 2013). As the river returned to a free-flowing state, these habitat parameters were expected to change unfavorably for Largemouth Bass. For example, water velocities were significantly higher during the spring post- removal and may explain how the interaction between season and dam removal affected abundance. Largemouth Bass may have avoided the increased water velocities during the spring but utilized the same reaches at base flows during the fall, creating a seasonally dependent response to dam removal.

The decrease in Largemouth Bass abundance following dam removal during the spring may impact future recruitment as it coincided with a decrease in total length. Although a decrease in size often points to smaller fish entering the population via recruitment, it is more likely that larger fish left the population in this situation. Despite a large drop in total length, the PSD value only dropped slightly following dam removal (Table 4). This indicates the stock was still made of mostly quality fish and that the decreased size is likely from the loss of memorable or trophy sized fish. These larger fish represent sexually mature individuals, and the absence of them following dam removal during spawn suggests recruitment of Largemouth Bass will suffer in the future.

As with Smallmouth Bass, it is likely the change in Largemouth Bass abundance following dam removal was driven by habitat selection behavior. Largemouth Bass avoided higher water velocities seen during the spring following dam removal, and the data suggest larger fish were disproportionately missing from the post-removal surveys. This behavioral shift may result in additional decreases as time goes on as sexually mature fish disappear from the population and recruitment suffers.

Implications- There are many concerns to be addressed surrounding dam removal and its effect on lotic fish communities. Public opposition may arise from anglers for fear of losing fishing opportunity. Trade-offs associated with dam removal may include short-term effects of sediment release or new connectivity facilitating the movement of non-native species (Doyle et al. 2000). Restoration timelines and trajectories may be hard to be predict given the wide range of variables affecting natural processes associated with the movement of stored sediment or the carving of a new channel (Doyle et al. 2005). Thus, increasing the number of long-term dam removal case studies using pre-removal and post-removal data is important to provide natural resource managers with sound information when making decisions involving specific projects. Specifically, comprehensive studies informing potential costs and benefits of dam removal, the feasibility of restoration objectives surrounding dam removal, and case studies with which to address stakeholder concerns about sportfish are needed. My study provides valuable information to reference on the immediate response of three sympatric black bass populations in a mid-sized river system to dam removal and suggests restored flow regime will benefit Smallmouth Bass, be detrimental to Largemouth Bass, and negligibly affect Spotted Bass populations.

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<A> Tables

Table 1: Results of a two-way ANOVA with fixed factors of dam removal and reach on water velocity and habitat scores. Asterisk indicates significant values ($P < 0.05$).

Variable	MS	DF	F Value	P-value
Spring Water Velocity				
Dam Removal	0.8664	1	10.474	0.0046
Reach	0.281	2	1.6987	0.211
Dam Removal x Reach	0.0433	2	0.2616	0.7727
Fall Water Velocity				
Dam Removal	0.0375	1	0.7448	0.3910
Reach	0.4073	2	8.0977	0.0007
Dam Removal x Reach	0.0053	2	0.1050	0.9005
QHEI Score				
Dam Removal	101.53	1	2.3379	0.1367
Reach	1460.15	2	33.6221	2.182E-08
Dam Removal x Reach	60.67	2	1.3969	0.2630

Table 2: Results of a nested ANOVA with fixed factors of reach, season, and dam removal on black bass abundance. Asterisk indicates significant values (P < 0.05).

Variable	MS	DF	F Value	P-value
Smallmouth Bass				
Reach	1.0385	2	8.1275	0.0005*
Season	1.1338	1	8.8736	0.0036*
Dam Removal	0.5792	1	4.5329	0.0357*
Reach x Season	0.1092	2	0.8542	0.4287
Reach x Dam Removal	0.0555	2	0.4346	0.6488
Season x Dam Removal	1.8846	1	14.7495	0.0002*
Spotted Bass				
Reach	0.2481	2	1.2729	0.2844
Season	1.7278	1	8.8658	0.0036*
Dam Removal	0.0365	1	0.1874	0.666
Reach x Season	0.0259	2	0.1328	0.8758
Reach x Dam Removal	0.0433	2	0.222	0.8013
Season x Dam Removal	0.1055	1	0.5411	0.4637
Largemouth Bass				
Reach	0.0059	2	0.0349	0.9657
Season	0.4407	1	2.5936	0.1104
Dam Removal	0.654	1	3.8488	0.0525
Reach x Season	0.1206	2	0.7096	0.4942
Reach x Dam Removal	0.3583	2	2.1086	0.1267
Season x Dam Removal	1.1617	1	6.8363	0.0103*

Table 3: Results of a Wilcoxon rank-sum test on total length and relative condition pre- and post-removal for each black bass species. Asterisk indicates significant values ($P < 0.05$).

Species	Pre-removal	Post-removal	W	P-value
Smallmouth Bass				
Total Length (mm)	210.05	212.19	3025.5	0.7424
Median Length (mm)	178.5	195		
Relative Condition (Kn)	1.02	1.01	2400	0.0641

Species	Pre-removal	Post-removal	W	P-value
Spotted Bass				
Total Length (mm)	103.23	100.37	2460	0.0292*
Median Length (mm)	84	95		
Relative Condition (Kn)	1.01	1.01	404	0.6616

Species	Pre-removal	Post-removal	W	P-value
Largemouth Bass				
Total Length (mm)	195.82	145.43	2474	0.0083*
Median Length (mm)	192	100		
Relative Condition (Kn)	1.02	1.01	682	0.9835

Table 4: Results of a Pearson's Chi-square test on PSD values pre- and post-removal for each black bass species. Asterisk indicates significant values ($P < 0.05$).

Species	Pre-removal	Post-removal	DF	X^2	P-value
Smallmouth Bass	74.074	87.76	2	3.073	0.2151
Spotted Bass	89.47	14.29	2	13.576	0.0011*
Largemouth Bass	85.37	80	2	0.175	0.9162

<A> Figures

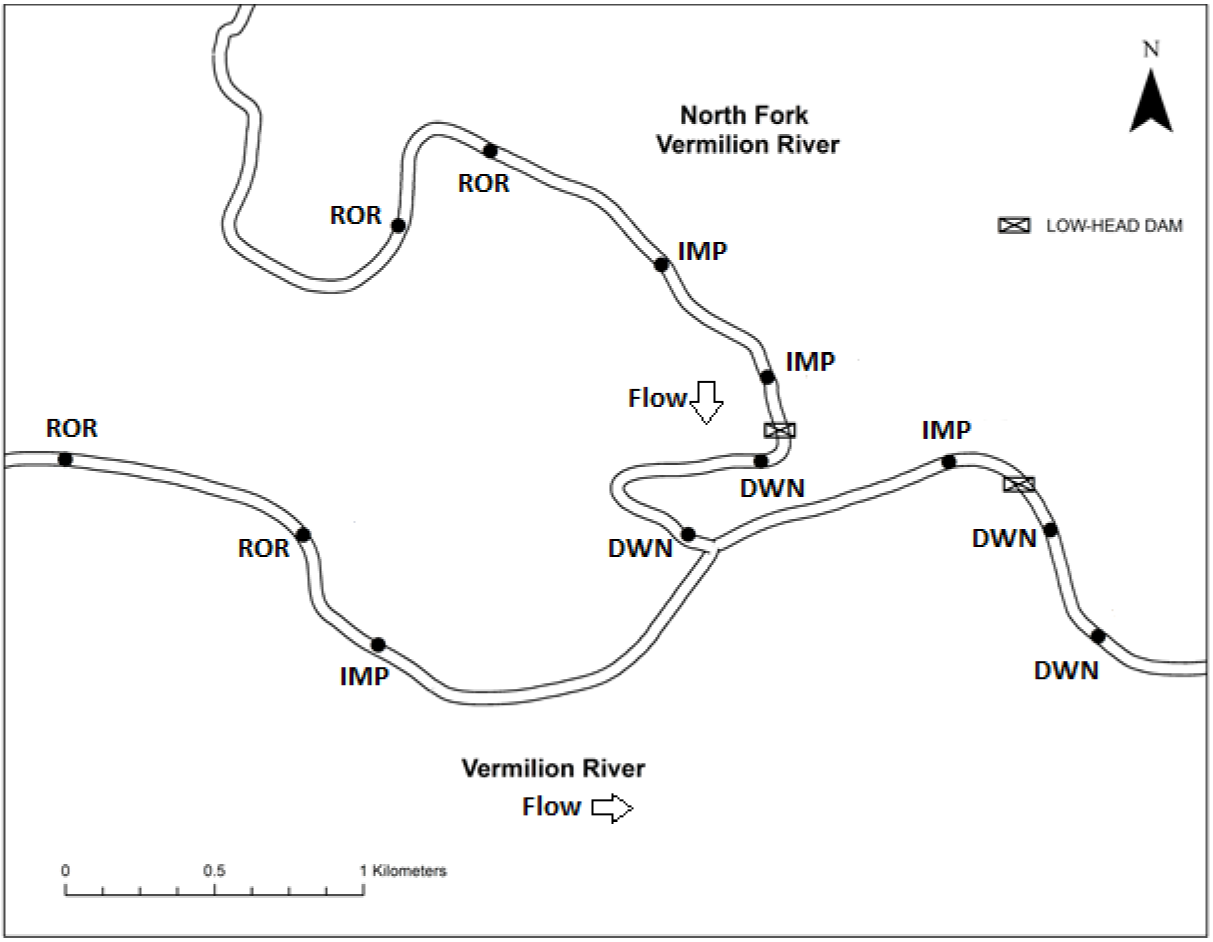


Figure 1. Study area with sampling locations on the Vermilion River and North Fork Vermilion River in relation to dam structures (ROR= run-of-river, IMP= impounded, DWN= downstream).

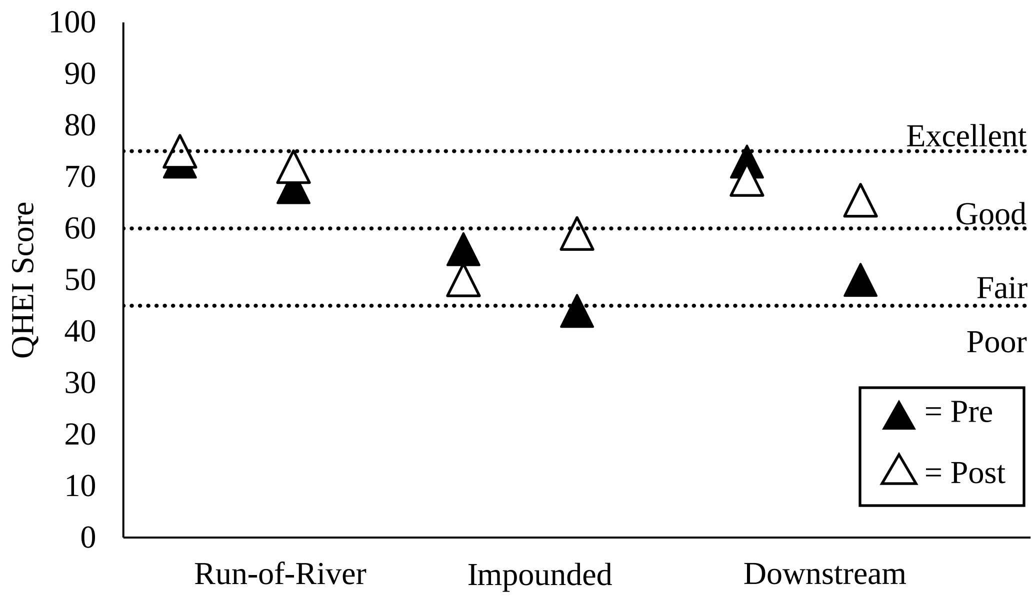


Figure 2. Qualitative Habitat Evaluation Scores before and after dam removal on the Vermilion River.

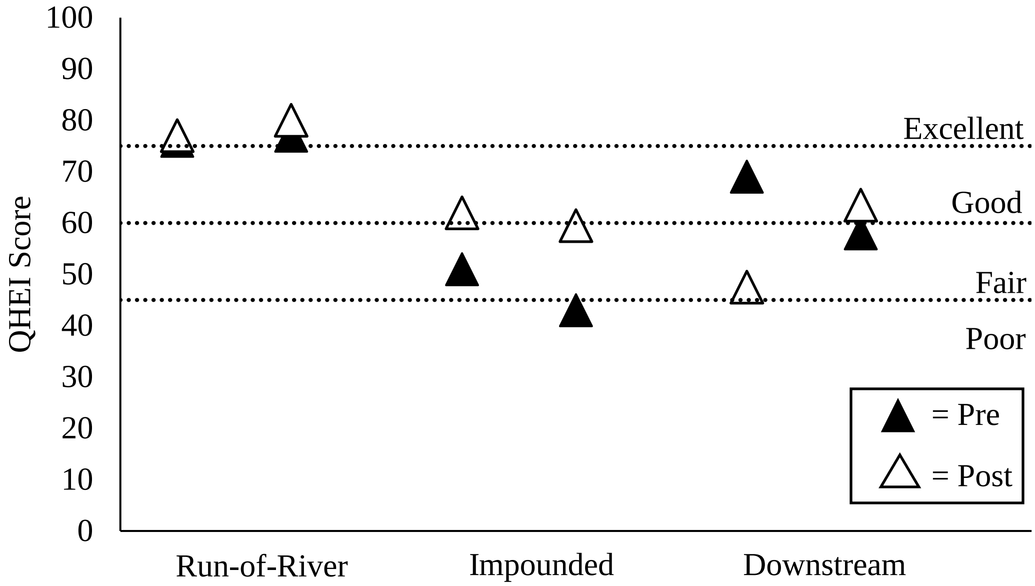


Figure 3. Qualitative Habitat Evaluation Scores before and after dam removal on the North Fork Vermilion River.

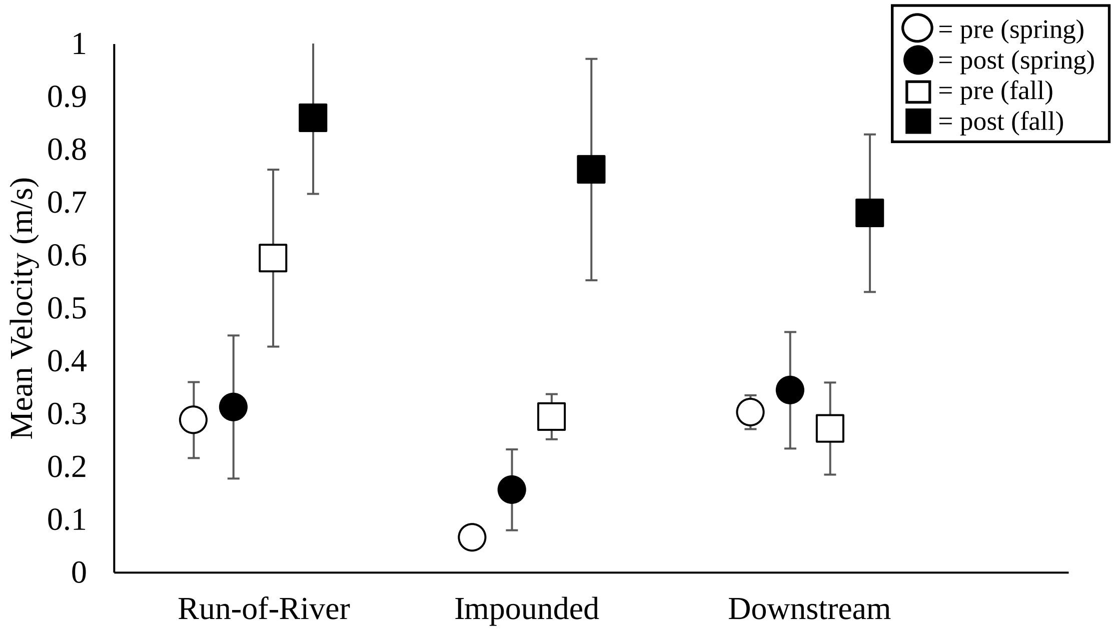


Figure 4. Pre-removal and post-removal water velocities (m/s) separated by reach during spring and fall sampling on the Vermilion River and North Fork Vermilion River with significant differences between pre and post removal values in the spring and significant differences between values within reaches during the fall.

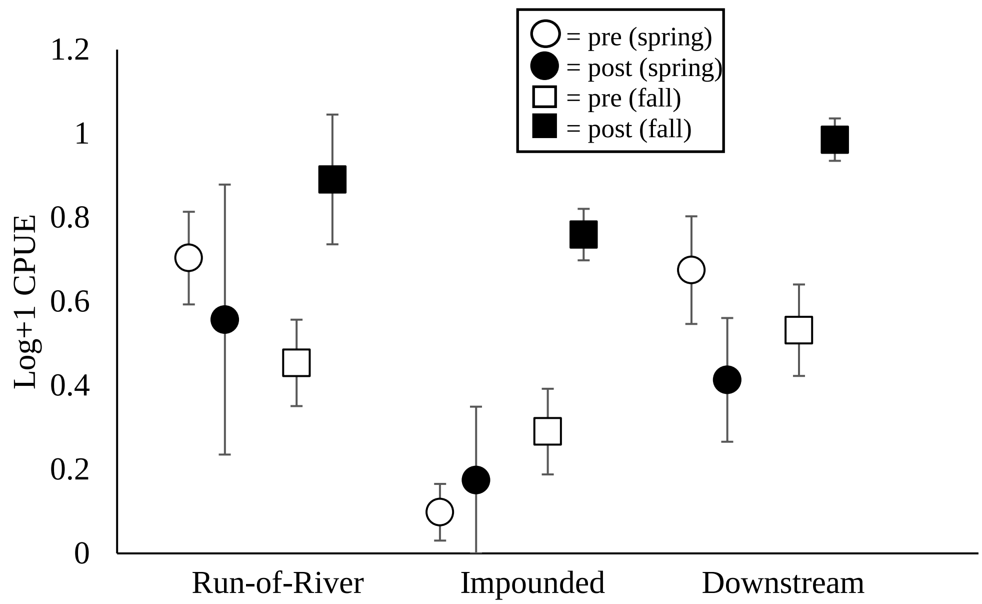


Figure 5. Pre-removal and post-removal Smallmouth Bass log+1 CPUE (fish/hr) separated by reach during spring and fall sampling on the Vermilion River and North Fork Vermilion River, with significant differences by reach, season, dam removal, and the interaction of season and dam removal. Significant factors affecting abundance are found in Table 2.

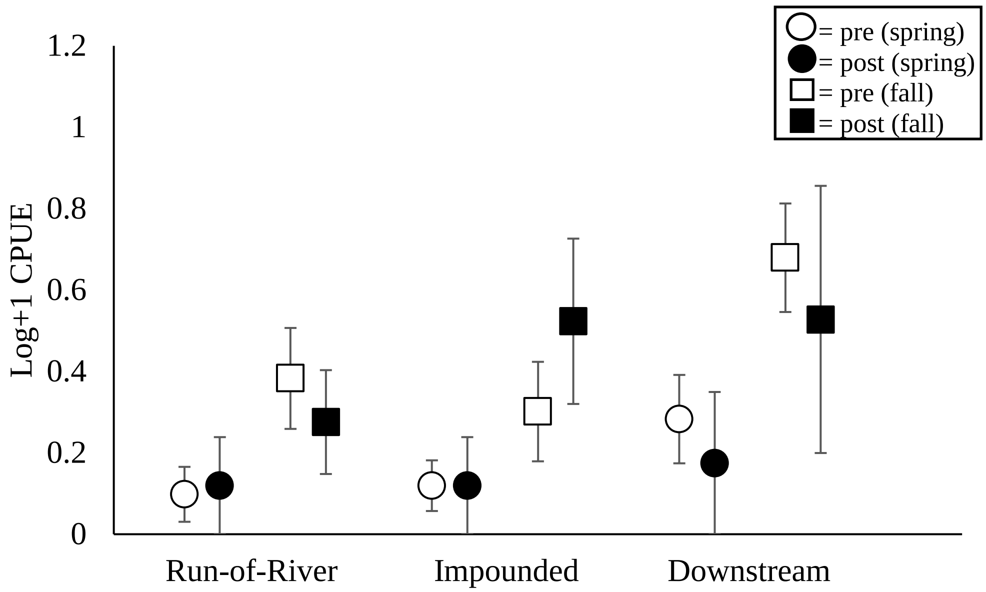


Figure 6. Pre-removal and post-removal Spotted Bass log+1 CPUE (fish/hr) separated by reach during spring and fall sampling on the Vermilion River and North Fork Vermilion River, with significant differences by reach, season, dam removal, and the interaction of season and dam removal. Significant factors affecting abundance are found in Table 2.

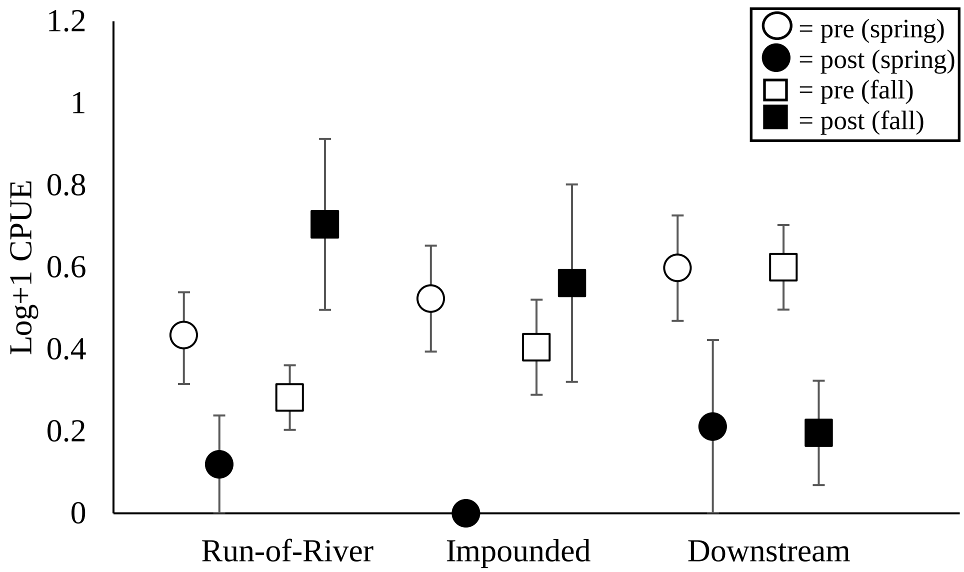
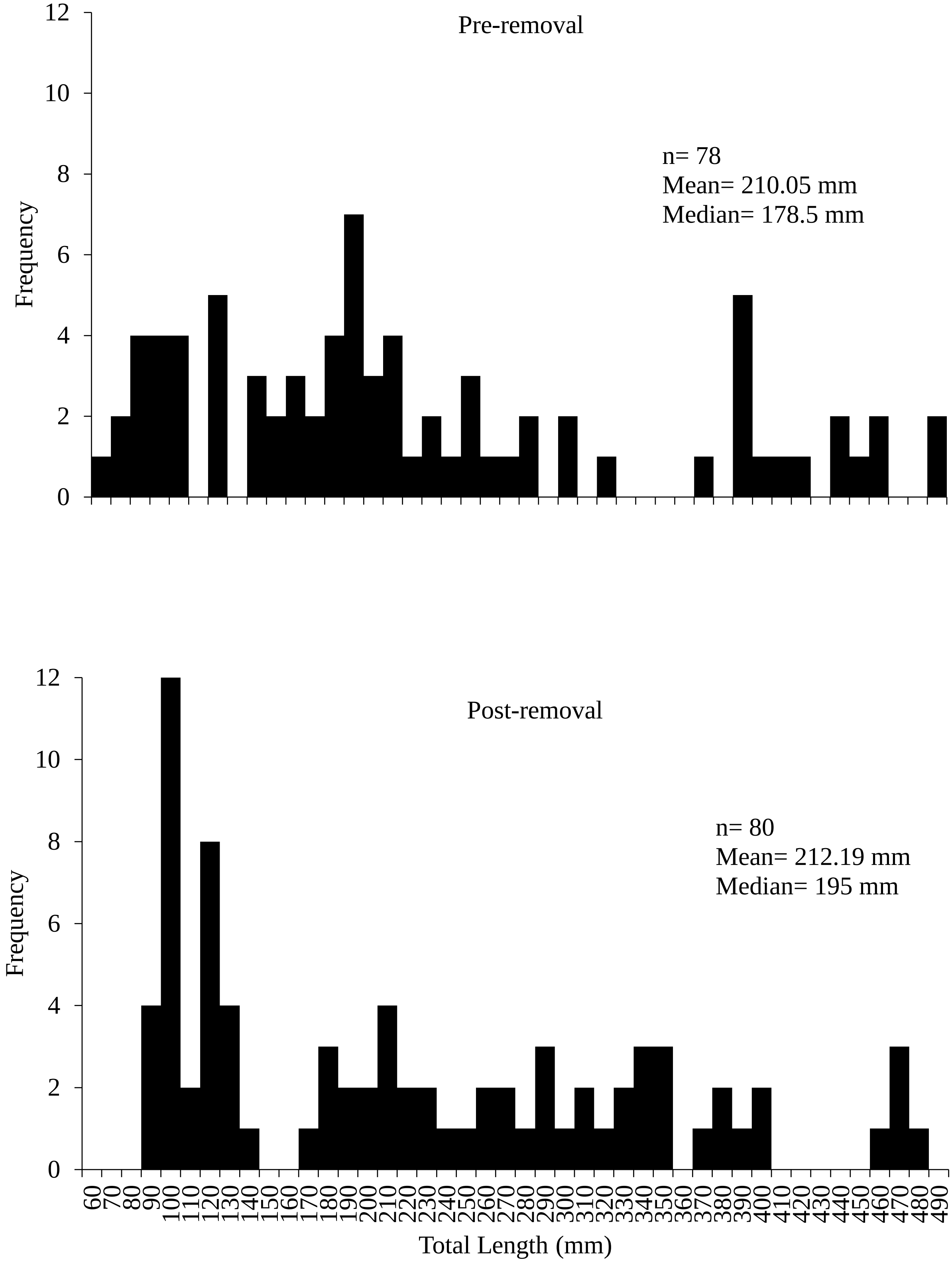


Figure 7. Pre-removal and post-removal Largemouth Bass log+1 CPUE (fish/hr) separated by reach during spring and fall sampling on the Vermilion River and North Fork Vermilion River, with significant differences by reach, season, dam removal, and the interaction of season and dam removal. Significant factors affecting abundance are found in Table 2.

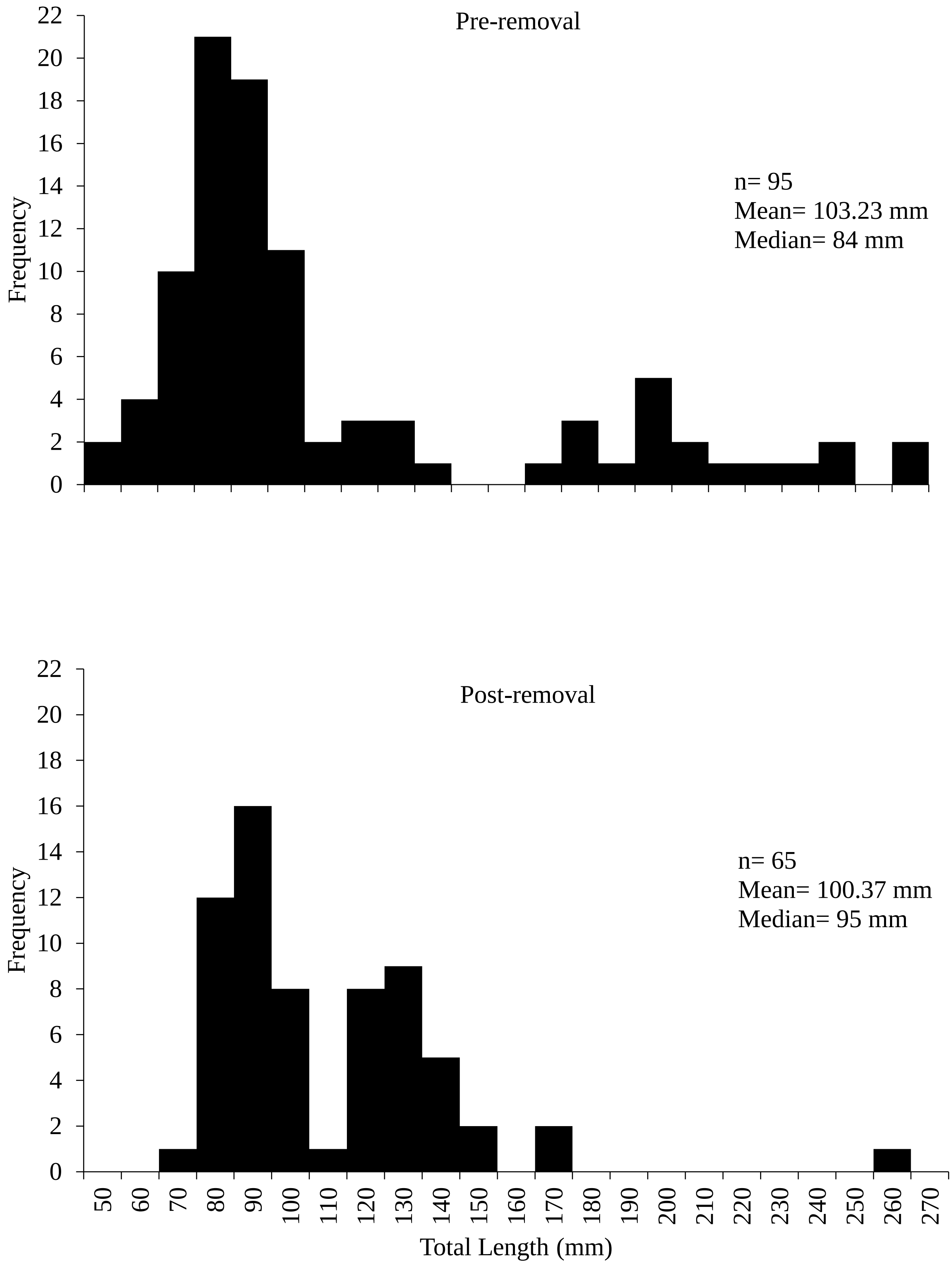
<A> Appendix

1. Results of a Kolmogorov-Smirnov test on pre- and post-removal size distributions of each black bass species.

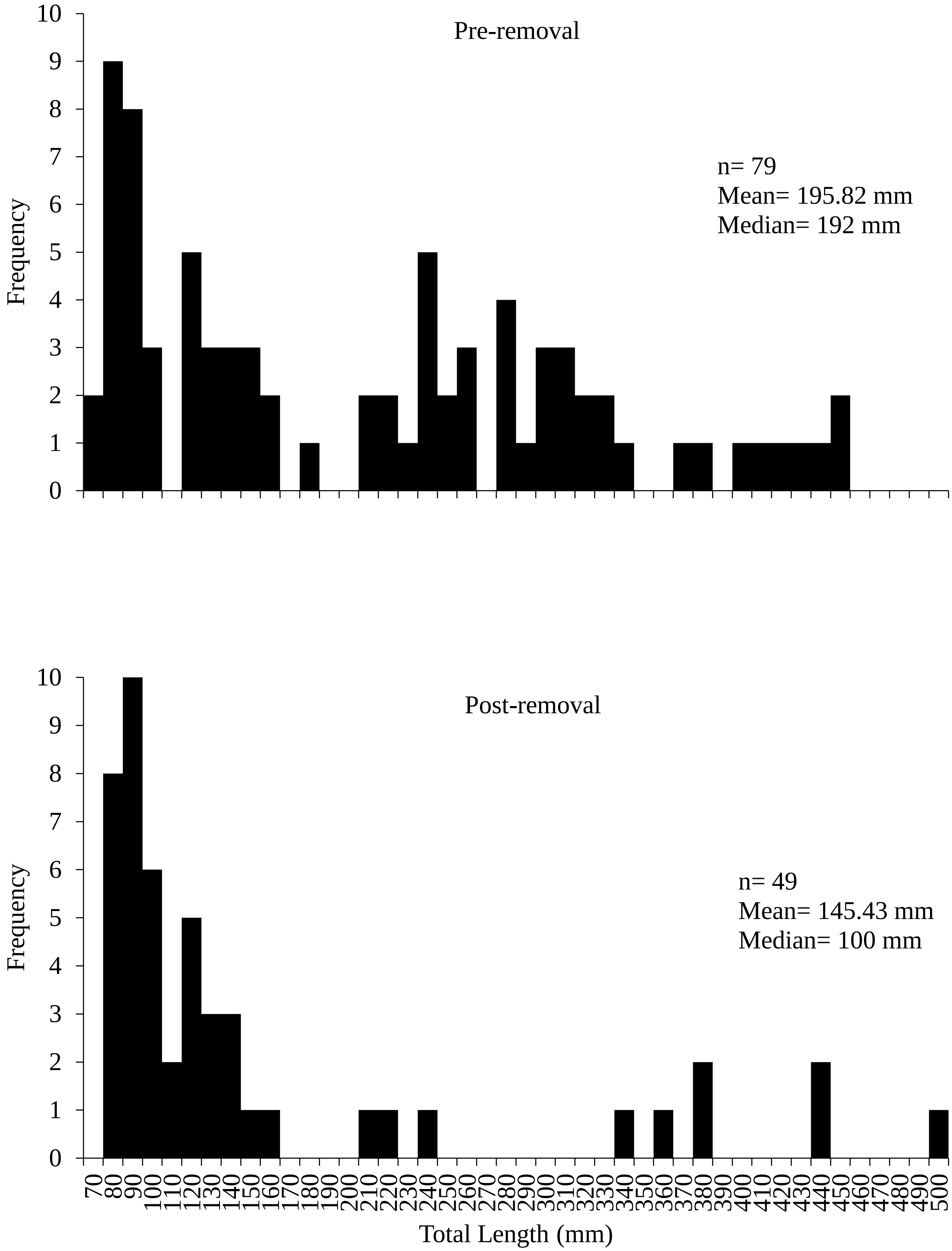
Species	D	P-value
Smallmouth Bass	0.338	0.0019*
Spotted Bass	0.2429	0.021*
Largemouth Bass	0.3451	0.0015*



2. Length-frequency histograms for Smallmouth Bass pre- and post-removal.



3. Length-frequency histograms for Spotted Bass pre- and post-removal.



4. Length-frequency histograms for Largemouth Bass pre- and post-removal.